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(54) **VIBRATION-DAMPING COMPONENTS, GAS TURBINE ENGINE AND METHOD OF FORMING SUCH COMPONENTS**

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F04D 29/38	(2006.01)
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(58) **Field of Classification Search**

None

See application file for complete search history.

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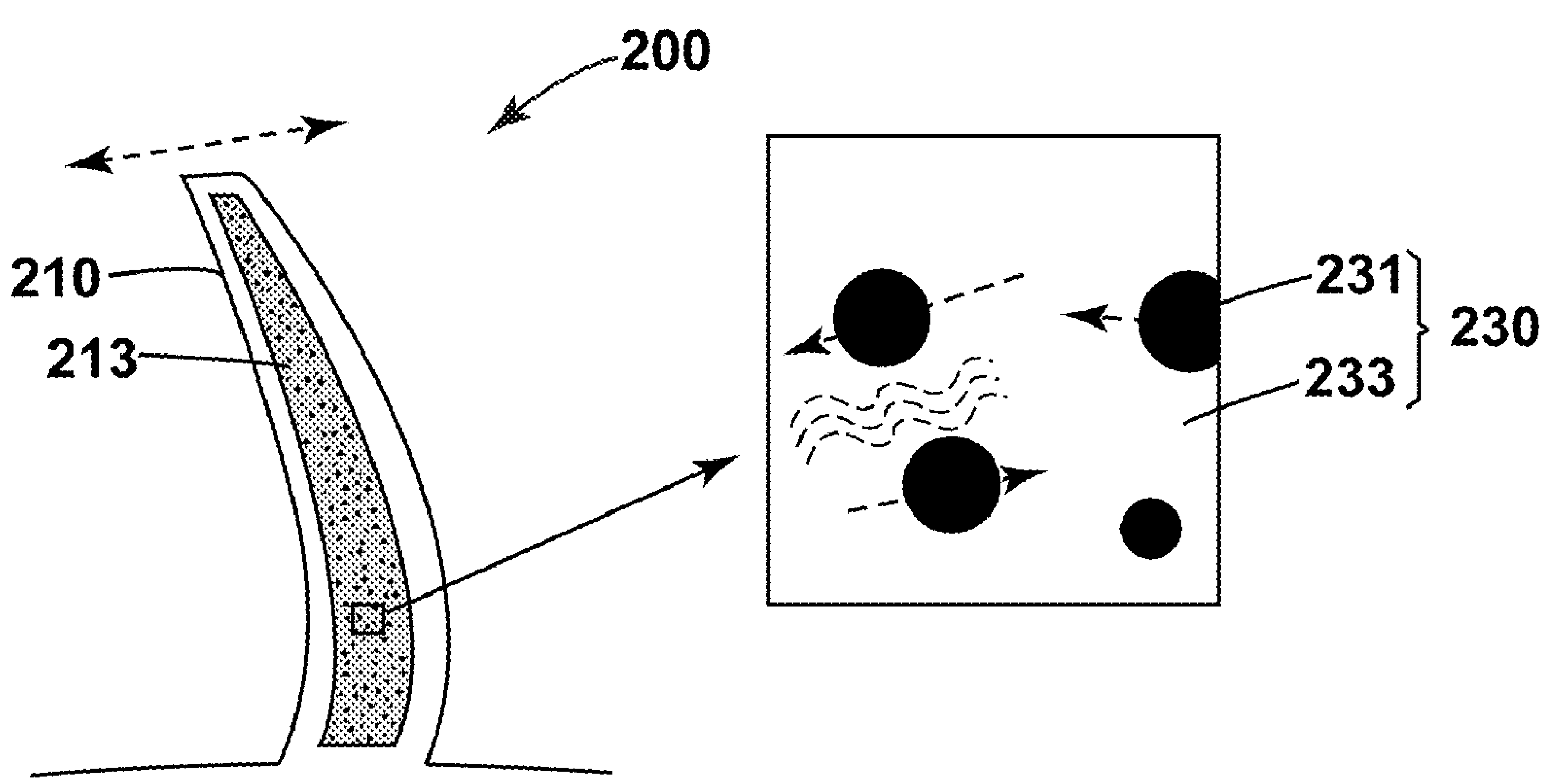
(57) **ABSTRACT**

A vibration-damping component, a gas turbine engine having the vibration-damping component and a method for forming such component are disclosed. The vibration-damping component comprises a body formed from an additive manufacturing material by an additive manufacturing process and defining a cavity within the body, and a vibration damper disposed within the cavity. The vibration damper comprises a damping element and a damping medium containing a viscoelastic material surrounding the damping element. The damping element has a relative motion when the component vibrates.

13 Claims, 4 Drawing Sheets



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B22F 3/00	(2006.01)
F23R 3/28	(2006.01)
B22F 3/105	(2006.01)
B29C 64/00	(2017.01)
B22F 7/08	(2006.01)
B22F 5/00	(2006.01)
F01D 5/28	(2006.01)
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B33Y 10/00	(2015.01)
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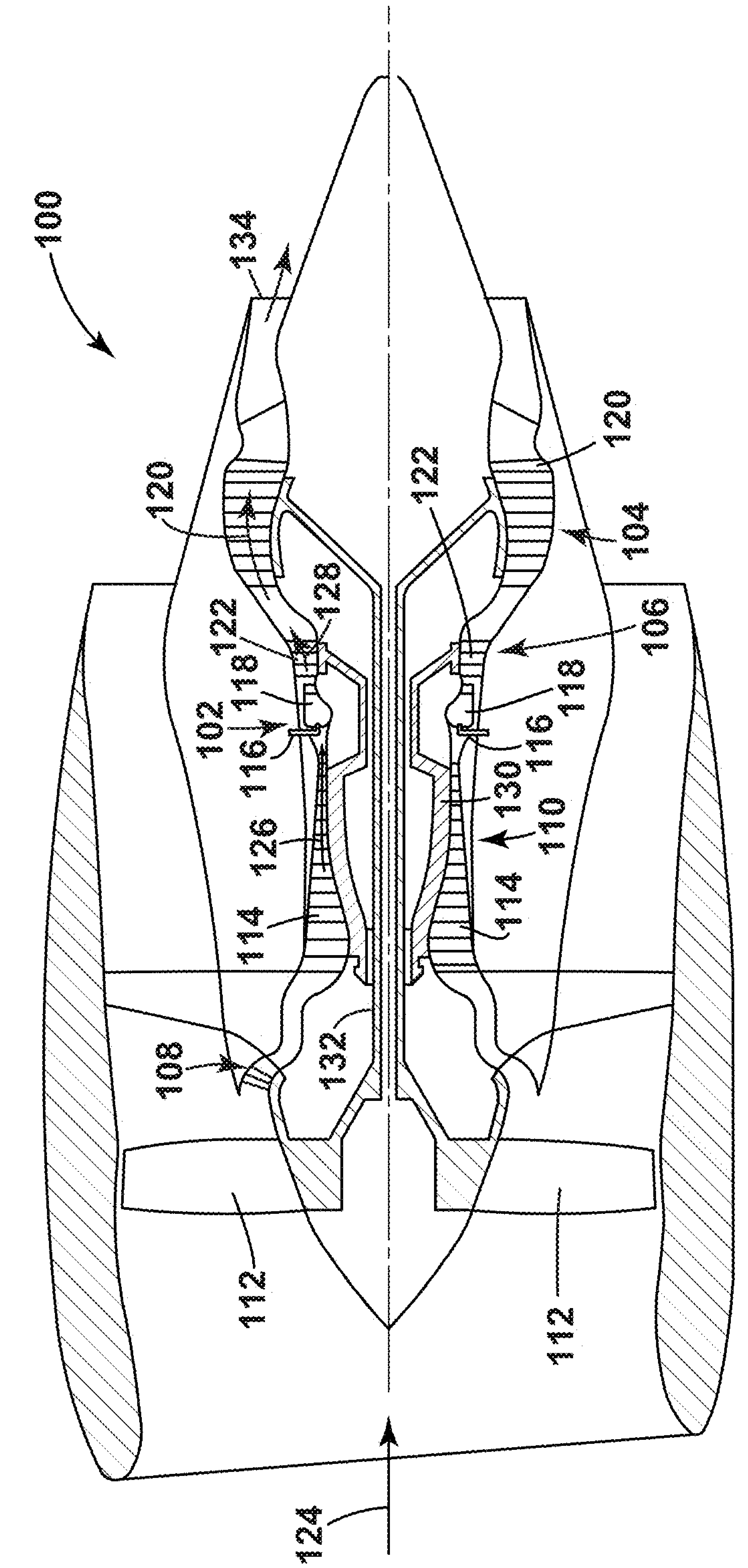
100
134
120
120
122
104
128
122
106
118
102
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108
132
112
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124

FIG. 1

FIG. 2

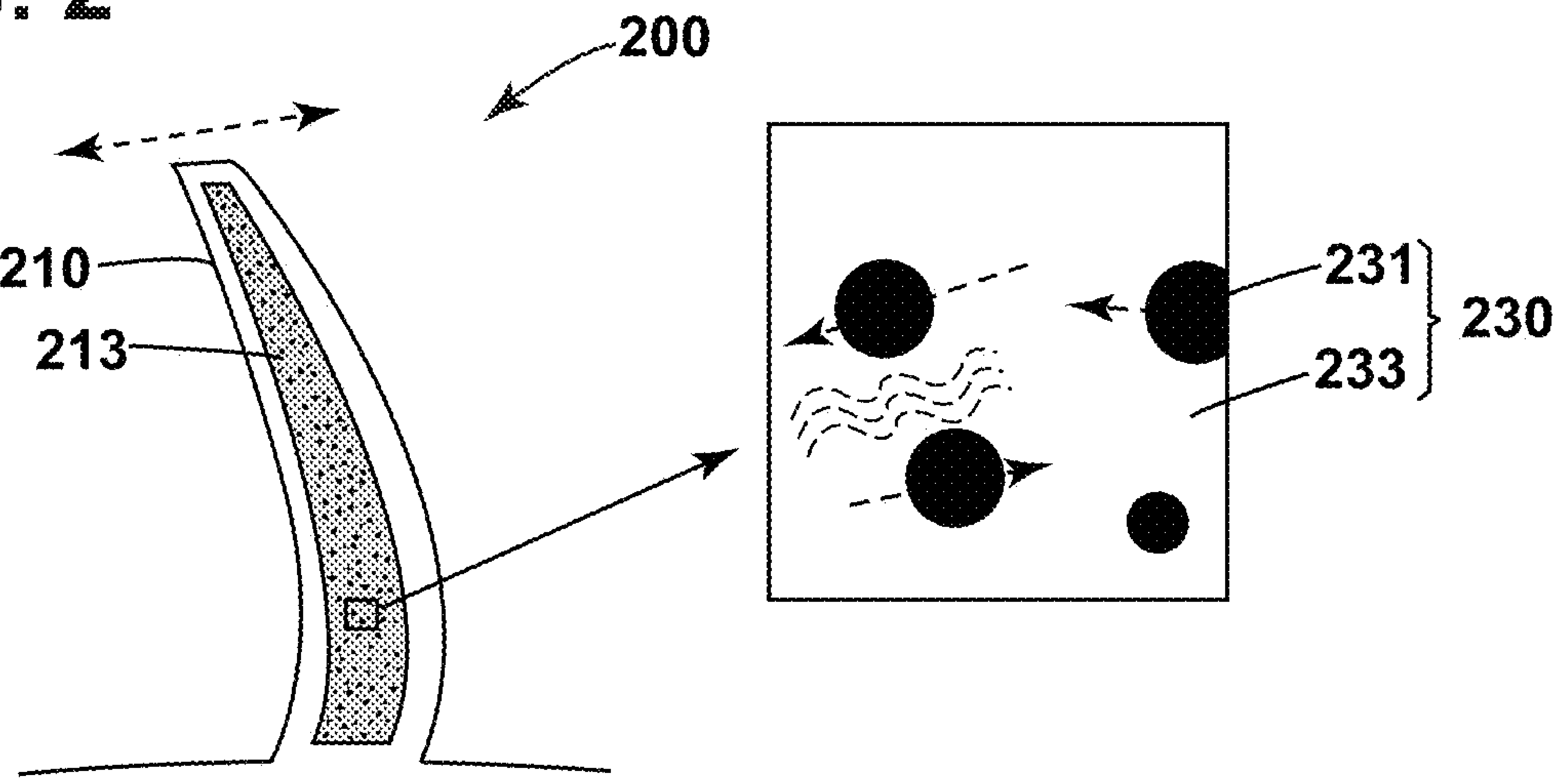


FIG. 3

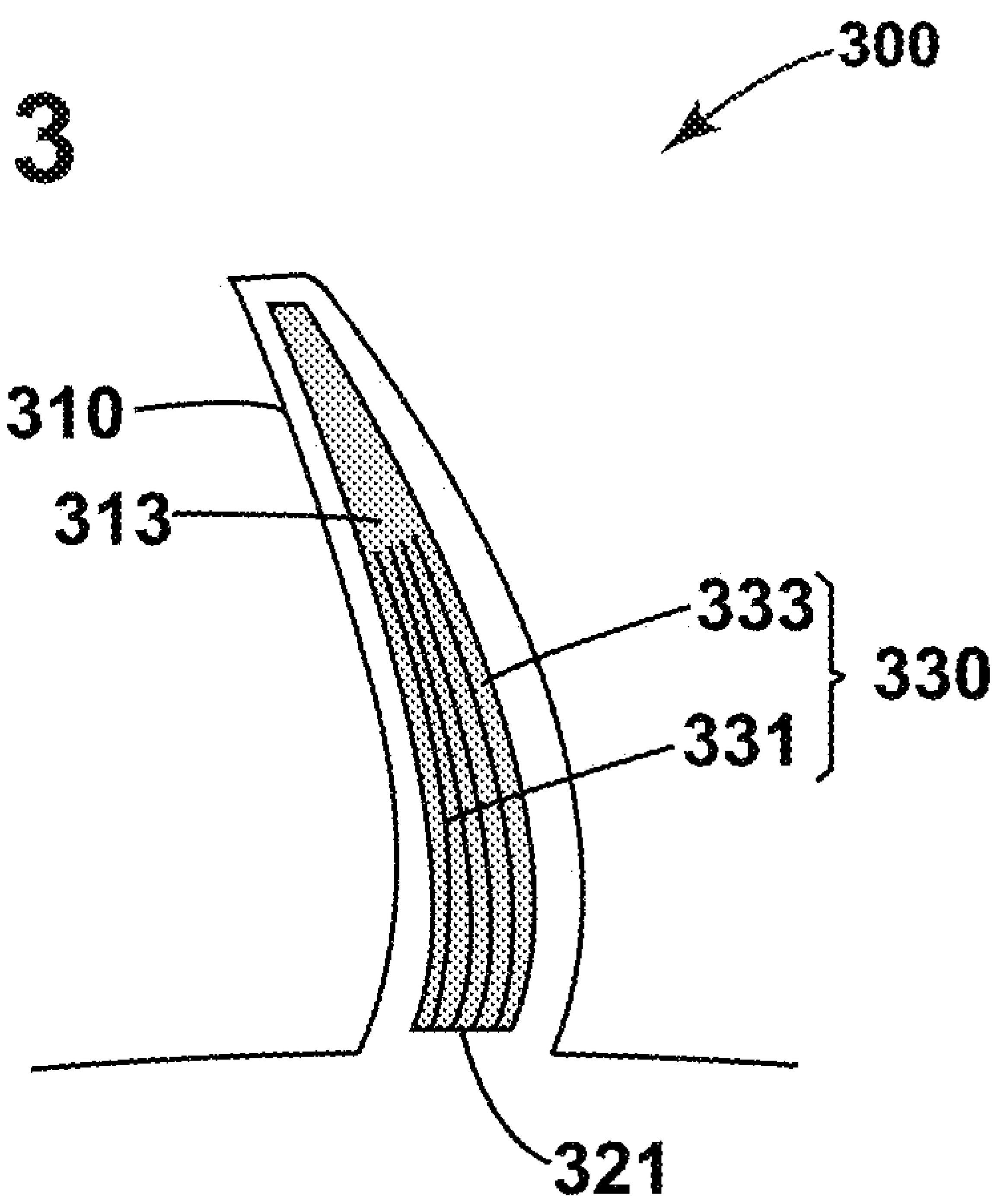


FIG. 4

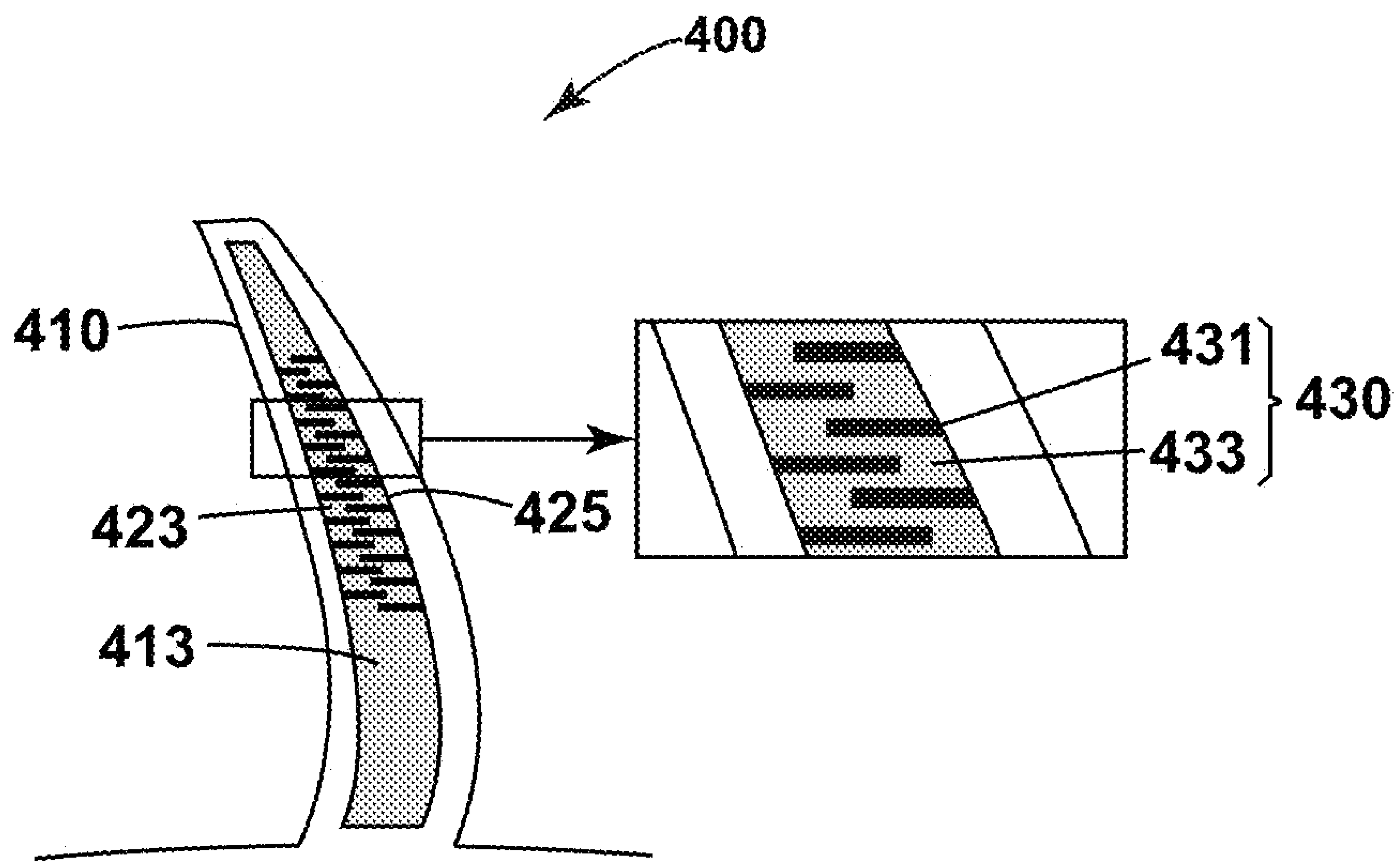

400
410
423
425
413
431
433
430

FIG. 5

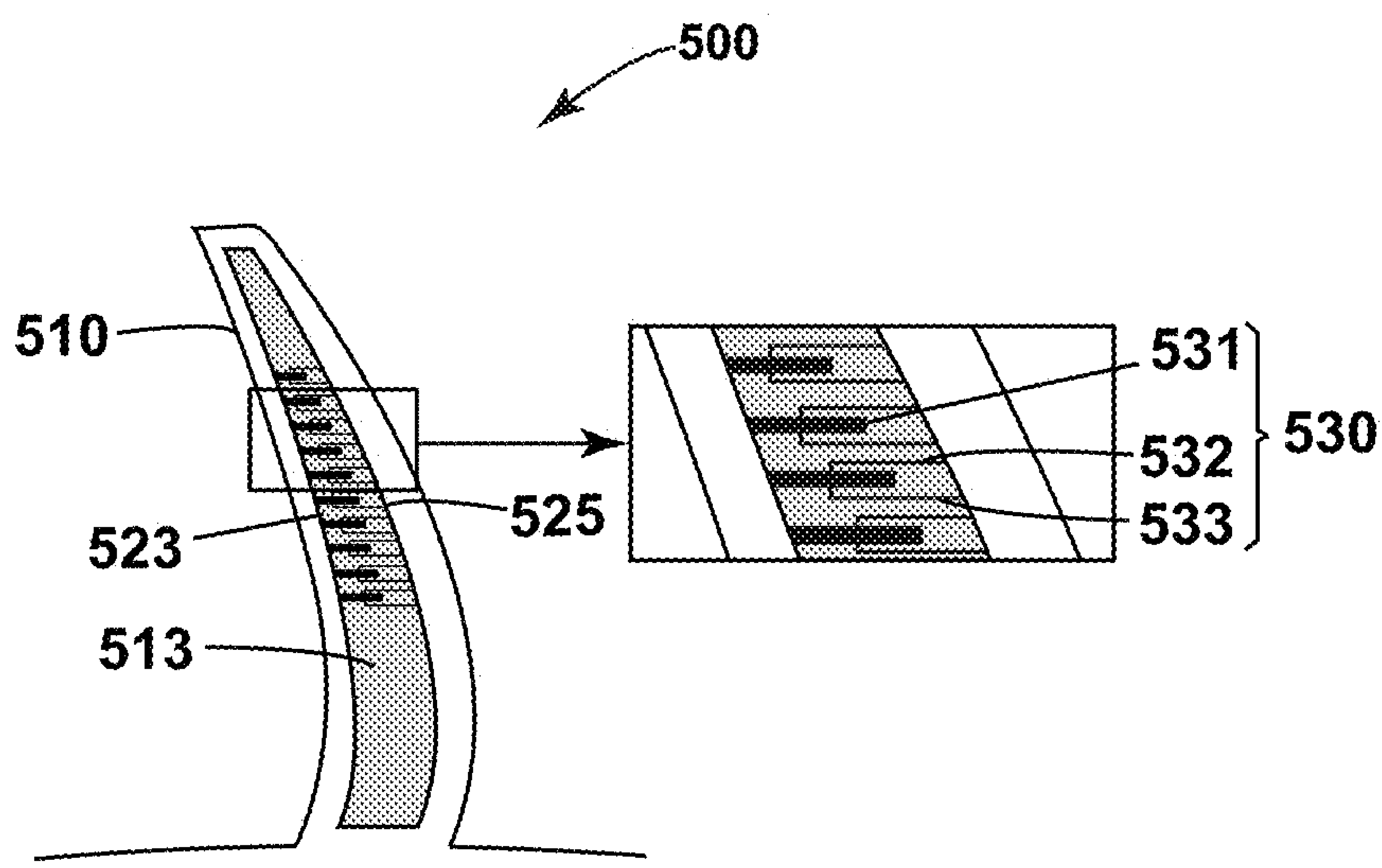
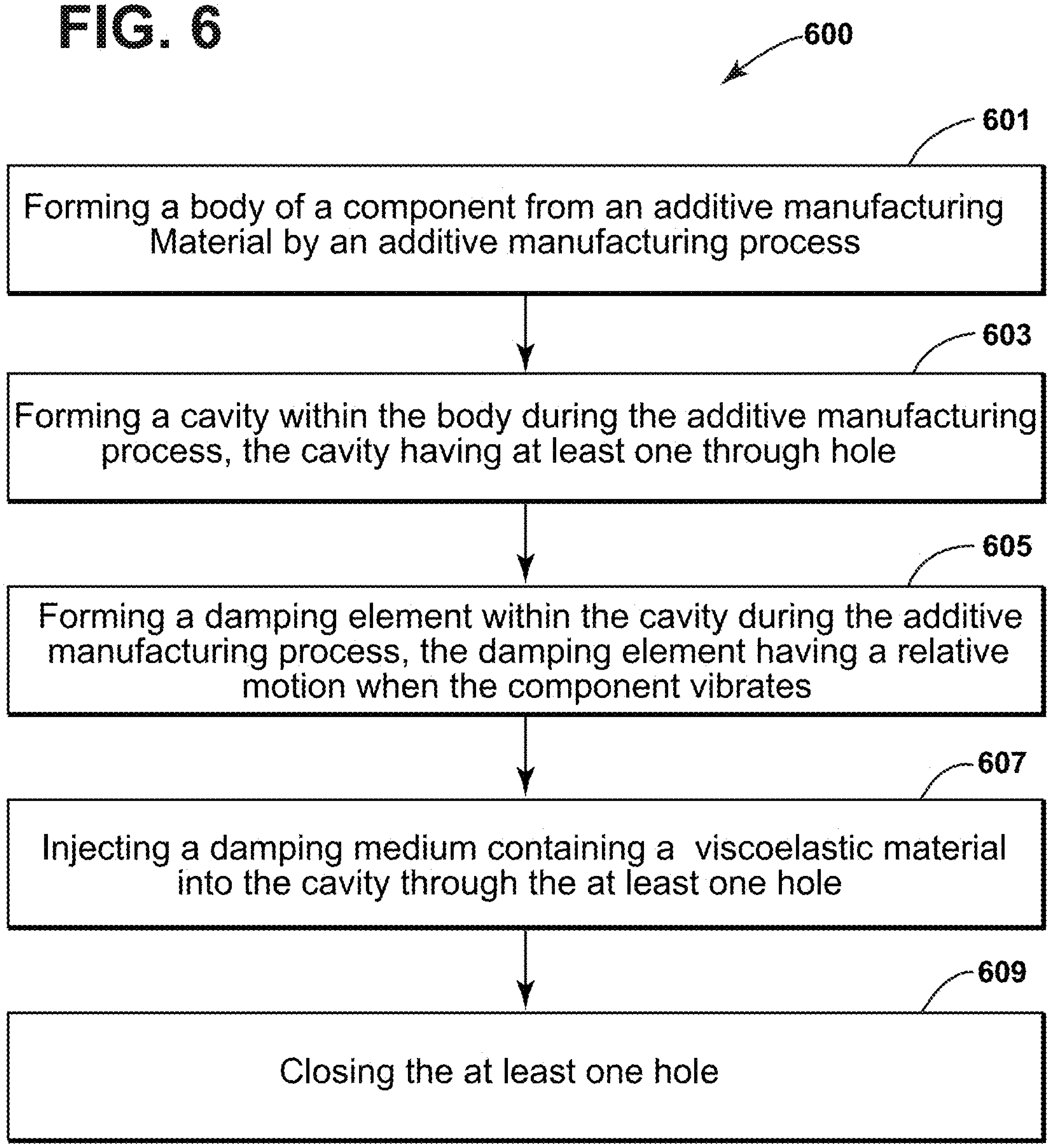

500
510
523
525
513
531
532
533
530

FIG. 6


600
601
Forming a body of a component from an additive manufacturing Material by an additive manufacturing process
603
Forming a cavity within the body during the additive manufacturing process, the cavity having at least one through hole
605
Forming a damping element within the cavity during the additive manufacturing process, the damping element having a relative motion when the component vibrates
607
Injecting a damping medium containing a viscoelastic material into the cavity through the at least one hole
609
Closing the at least one hole

VIBRATION-DAMPING COMPONENTS, GAS TURBINE ENGINE AND METHOD OF FORMING SUCH COMPONENTS

BACKGROUND

This invention relates generally to vibration-damping components, gas turbine engine having the vibration-damping component and methods of forming such components.

Vibration of mechanical components may induce component fatigue and excessive localized noise within mechanical systems. Accordingly, reducing vibrational loading of mechanical components within such mechanical systems is a priority among producers and users of such systems.

Take turbine blades of a gas turbine engine as an example, during engine operation, turbine blades are exposed to a wide variety of stresses due to heat, oscillating airflow, etc. and correspondingly exhibit many adverse vibration modes and manners of operation. As a consequence, large stresses are induced in the blades and other elements of the turbine engine. Thus, damping needs to be introduced to offset these adverse consequences in order to reduce or even eliminate these stresses.

Various attempts have been made to provide damping to such components. For example, in some prior arts, damping materials or dampers have been placed in cavities of the component to reduce or alter vibrational modes. Usually, the dampers may comprise powders, particles, or one or more solidified elements. The solidified element may have various shapes and structures. Furthermore, the solidified element may be free-floating in the cavity or attached to an internal wall of the cavity. As for manufacturing methods of a component with vibration dampers enclosed therein, traditional ways include casting, forging machining, gluing, welding, brazing, or combinations of those methods. For example, it may require the two sides of the component be formed separately and bonded together around a vibration damper. An advanced way is to use an additive manufacturing process to form a component having at least one cavity enclosed and introduce a damper into the cavity during the additive manufacturing process. The additive manufacturing process is more suitable to form a component with complex interior geometries.

However, such known dampers-included cavities incorporated into mechanical components generally do not reduce vibrational loading of such components to a satisfactory level. Accordingly, there remains a need to further improve vibration damping of the mechanical components through placing more effective internal dampers in the cavities of the mechanical components.

BRIEF DESCRIPTION

This need is addressed by the present invention, which provides vibration-damping components, gas turbine engines having the vibration-damping component, and methods of forming such components, which are effective to improve vibration damping performance of the components.

In one aspect, a vibration-damping component is provided. The component comprises a body formed from an additive manufacturing material by an additive manufacturing process and defining a cavity within the body, and a vibration damper disposed within the cavity. The vibration damper comprises a damping element which has a relative motion when the component vibrates, and a damping medium containing a viscoelastic material surrounding the damping element.

In another aspect, a gas turbine engine is provided. The gas turbine engine includes a combustor assembly, a turbine assembly, and a compressor assembly. The combustor assembly includes a plurality of fuel mixers. The turbine assembly includes a plurality of turbine blades. The compressor assembly includes a plurality of fan blades. At least one of fuel mixers, turbine blades, and fan blades comprises a vibration-damping component. The vibration-damping component comprises a body formed from an additive manufacturing material by an additive manufacturing process and defining a cavity within the body, and a vibration damper disposed within the cavity. The vibration damper comprises a damping element which has a relative motion when the component vibrates, and a damping medium containing a viscoelastic material surrounding the damping element.

In yet another aspect, a method of forming a vibration-damping component is provided. The method comprises forming a body of the component from an additive manufacturing material by an additive manufacturing process; forming a cavity within the body during the additive manufacturing process, the cavity having at least one through hole; forming a damping element within the cavity during the additive manufacturing process; injecting a damping medium containing a viscoelastic material into the cavity through the at least one through hole; and closing the at least one through hole. The damping element has a relative motion when the component vibrates.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

FIG. **1** is a schematic illustration of an exemplary gas turbine engine;

FIG. **2** is a schematic illustration of an exemplary vibration-damping component in accordance with a first embodiment of the present invention;

FIG. **3** is a schematic illustration of an exemplary vibration-damping component in accordance with a second embodiment of the present invention;

FIG. **4** is a schematic illustration of an exemplary vibration-damping component in accordance with a third embodiment of the present invention;

FIG. **5** is a schematic illustration of an exemplary vibration-damping component in accordance with a fourth embodiment of the present invention;

FIG. **6** is a flowchart of an exemplary method of forming a vibration-damping component with an aspect of the present invention.

Unless otherwise indicated, the drawings provided herein are meant to illustrate features of embodiments of the disclosure. These features are believed to be applicable in a wide variety of systems comprising one or more embodiments of the disclosure. As such, the drawings are not meant to include all conventional features known by those of ordinary skill in the art to be required for the practice of the embodiments disclosed herein.

DETAILED DESCRIPTION OF THE INVENTION

In the following specification and the claims, reference will be made to a number of terms, which shall be defined to have the following meanings.

The singular forms "a", "an", and "the" include plural references unless the context clearly dictates otherwise.

Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about" and "substantially", are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Here and throughout the specification and claims, range limitations may be combined and/or interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise.

FIG. **1** is a schematic illustration of an exemplary gas turbine engine, indicated generally at **100**. In the exemplary embodiment, the gas turbine engine **100** includes a combustor assembly **102**, a low-pressure turbine assembly **104**, and a high-pressure turbine assembly **106**, collectively referred to as a turbine assembly. The gas turbine engine **100** also includes a fan **112**, a low-pressure compressor assembly **108** and a high-pressure compressor assembly **110**, generally referred to as a compressor assembly. In the exemplary embodiment, the gas turbine engine **100** is an aircraft engine, although in alternative embodiments, gas turbine engine **100** may be any other suitable gas turbine engine, such as an electric power generation gas turbine engine or a land-based gas turbine engine.

Low-pressure compressor assembly **108** and high-pressure compressor assembly **110** each include a plurality of fan blades respectively, for compressing ambient air flowing into gas turbine engine **100**. Combustor assembly **102** includes a plurality of fuel mixers **116** for mixing fuel with pressurized air and/or injecting fuel or an air/fuel mixture into a combustion chamber **118**. Low-pressure turbine assembly **104** and high-pressure turbine assembly **106** each include a plurality of turbine blades **120** and **122**, respectively.

In operation, ambient air, represented by arrow **124**, enters gas turbine engine **100** and is pressurized by low-pressure compressor assembly **108** and/or high-pressure compressor assembly **110**. Pressurized air, represented by arrow **126**, is mixed with fuel via fuel mixers **116**, and combusted within combustion chamber **118**, producing high-energy combustion products, represented by arrow **128**. Combustion products **128** flow from combustion chamber **118** to high-pressure turbine assembly **106** and drive high-pressure compressor assembly **110** via a first drive shaft **130**. Combustion products **128** then flow to low-pressure turbine assembly **104** and drive low-pressure compressor assembly **108** via a second drive shaft **132**. Combustion products **128** exit gas turbine engine **100** through an exhaust nozzle **134**, and provide at least a portion of the jet propulsive thrust of the gas turbine engine **100**.

The components of gas turbine engine **100** may be subjected to vibrational forces during operation, resulting in part from rotation of compressor assemblies **108** and **110** and turbine assemblies **104** and **106**, and the combustion of gases within gas turbine engine **100**.

FIG. **2** is a schematic illustration of an exemplary vibration-damping component **200** in accordance with a first embodiment of the present invention. In the illustrated embodiment, component **200** is a turbine blade **120** of gas turbine engine **100** shown in FIG. **1**, in particular, a hollow turbine blade, although in alternative embodiments, component **200** may be any other component of gas turbine engine **100**, such as fan blades **112** and **114** or fuel mixer **116**. In yet further alternative embodiments, component **200** may be a component other than a component of a gas turbine engine **100**.

Component **200** comprises a body **210** formed from an additive manufacturing material by an additive manufacturing process and defining a cavity **213** within the body. The additive manufacturing process (also known as rapid prototyping, rapid manufacturing, and 3D printing) comprises selective laser sintering (SLS) process, direct metal laser sintering (DMLS), electron beam melting (EBM), selective heat sintering (SHS), stereolithography (SLA), or any other suitable additive manufacturing process. Component **200** may be fabricated from any suitable additive manufacturing material, such as metal powder(s) (e.g., cobalt chrome, steels, aluminum, titanium and/or nickel alloys), gas atomized metal powder(s), thermoplastic powder(s) (e.g., polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and/or high-density polyethylene (HDPE)), photopolymer resin(s) (e.g., UV-curable photopolymers), thermoset resin (s), thermoplastic resin(s), or any other suitable material that enables component **200** to function as described herein. As used herein, the term "additive manufacturing material" includes any materials that may be used to fabricate a component by an additive manufacturing process, such as these additive manufacturing processes described above.

In some embodiments, component **200** may comprise more than one cavities **213** defined within the body **210** of component **200**. Component **200** may comprise any suitable number of cavities **213** that enables component **200** to function as described herein. Each cavity **213** is enclosed within the body **210** of component **200** and may have any suitable shape that enables component **200** to function as described herein. In the exemplary embodiment shown in FIG. **2**, component **200** has only one cavity **213** and the cavity **213** has a similar shape as the shape of the body **210**.

The cavity **213** includes a vibration damper **230** enclosed therein. The vibration damper **230** comprises a plurality of powders or particles **231** and a damping medium **233** containing a viscoelastic material surrounding the powders or particles **231**. The viscoelastic material exhibits viscoelasticity. Viscoelasticity is a property of a solid or liquid which, when deformed, exhibits both viscos and elastic behavior through the simultaneous dissipation and storage of mechanical energy. The viscoelastic material as used herein, is a name given to a class of materials that displays a stretching or elongation response usually referred to as a strain to an external stress that is dependent on the initial stress, on the strain, and on either the time rate of application of the stress or the time rate of change of the strain. The viscoelastic material acts as a strain-based damper and damps the vibrations of component **200** by removing energy from the vibrations due to its viscoelasticity. Any suitable viscoelastic material may be used as the damping medium, such as an epoxy resin, polyurethane or other suitable polymer. For example, some typical viscoelastic materials which can be used for internal damping of a component include adhesive films, such as 3M 507FL, 3M AF191, and MSC 104 manufactured by 3M Bonding Systems. Usually the viscoelastic material is flowable at an elevated temperature. The damping medium **233** containing a flowable viscoelastic material may be injected into cavity **213** after the cavity **213** is almost formed.

As shown in FIG. **2**, powders or particles **231** are suspended in damping medium **233** containing the viscoelastic material. In the exemplary embodiment, powders or particles **231** usually have a particle size in a range of 5-1000 microns, preferably in a range of 10-500 microns. Since the body **210** of component **200** is fabricated by an additive manufacturing process, the powders or particles **231** may be introduced into the cavity **213** during the additive manufacturing process. The composition of powders or particles **231** may be selected from metal, ceramic, thermoplastic, or a combination thereof. In one embodiment, the powders or particles **231** comprise a part of unsolidified additive manufacturing material used for fabricating the body **210**. Thus, a part of the unsolidified additive manufacturing material is selectively left in the cavity **213** during the additive manufacturing process. In alternative embodiments, the powders or particles **231** may comprise a material other than the additive manufacturing material used for fabricating component **200**. In addition, the powders or particles **231** may have any suitable shapes, such as spherical, cylindrical, cubic, acicular, and flakey.

As shown in FIG. **2**, as component **200** vibrates, the powders or particles **231** have a relative motion, which may induce shear into the damping medium **233** containing a viscoelastic material and results in more dissipation of energy.

FIGS. **3**-**5** are schematic illustration of exemplary vibration-damping components **300**, **400**, and **500** in according with a second, a third and a fourth embodiment of the present invention respectively. Each of vibration-damping components **300**, **400**, and **500** is substantially identical to component **200** (shown in FIG. **2**) having a body with a cavity and a damping medium containing a viscoelastic material within the cavity, with the exception that at least one solidified element is positioned in the cavity to replace power or particles **231** as the damping element. Each of the solidified elements has a first end coupled to an inner wall of the cavity and a second end cantilevered. The solidified elements may have various geometries, including rod, flat-plate, hollow tube, or any suitable geometries. When component **300**, **400**, and **500** vibrates, the solidified element inside its cavity has a relative motion, which induces shear into the damping medium containing a viscoelastic material, and results in more dissipation of energy.

As shown in FIG. **3**, component **300** comprises a body **310** defining a cavity **313** within the body. The cavity **313** includes a vibration damper **330** enclosed therein. The vibration damper **330** comprises a solidified element including multiple long rods **331** as the damping element and a damping medium **333** containing a viscoelastic material surrounding the multiple long rods **331**. Each of the multiple long rods **331** has one end coupled to an inner wall **321** of the cavity, and a second end cantilevered. In the exemplary embodiment, the multiple long rods **331** extend in a same direction substantially, so they are almost parallel to each other. In alternative embodiments, the multiple long rods **331** may extend in different directions. Furthermore, each of the multiple long rods **331** may have any suitable cross-sections, such as circular, oval, square, rectangular, and triangle, that enables the vibration damper **330** to function as described herein.

In the exemplary embodiment, the multiple long rods **331** are formed by the same additive manufacturing process used to fabricate the body **310** of component **300**. Thus, the multiple long rods **331** may be fabricated from the same additive manufacturing material used to fabricate the body **310**. In alternative embodiments, the multiple long rods **331** may be fabricated from a material other than the additive manufacturing material used to fabricate the body **310**.

As shown in FIG. **4**, component **400** comprises a body **410** formed from an additive manufacturing material by an additive manufacturing process and defining a cavity **413** within the body. The cavity **413** includes a vibration damper **430** enclosed therein. The vibration damper **430** comprises a solidified damping element including multiple short rods **431** and a damping medium **433** containing a viscoelastic material surrounding the multiple short rods **431**. In particular, a part of the multiple short rods **431** are attached to a first internal side wall **423** of the cavity **413**, and the other part of the multiple short rods **431** are attached to a second internal side wall **425** facing to the first internal side wall **423** of the cavity **413**. The two parts of the multiple short rods **431** at least partially intersect. Thus, an interwoven structure is formed by the multiple short rods **431**.

In the exemplary embodiment, the multiple rods **431** are formed by the same additive manufacturing process used to fabricate the body **410** of component **400**. Thus, the multiple rods **431** may be fabricated from the same additive manufacturing material used to fabricate the body **410**. In alternative embodiments, the multiple rods **431** may be fabricated from a material other than the additive manufacturing material used to fabricate the body **410**.

As shown in FIG. **5**, component **500** comprises a body **510** formed from an additive manufacturing material by an additive manufacturing process and defining a cavity **513** within the body. The cavity **513** includes a vibration damper **530** enclosed therein. The vibration damper **530** comprises two kinds of solidified damping elements and a damping medium **533** containing a viscoelastic material surrounding the solidified elements. One kind of the solidified elements are short rods **531** attached to a first internal side wall **523** of the cavity **513**. The other kind of the solidified elements are hollow tubes **532** attached to a second internal side wall **525** of the cavity **513** facing to the first internal side wall **523** of the cavity **513**. At least one short rod **531** is at least partially inserted into one of the hollow tubes **532**. The damping medium containing a viscoelastic material surrounds the short rods **531** and both inside and outside of the hollow tubes **532**.

In the exemplary embodiment, the short rods **531** and the hollow tubes **532** are formed by the same additive manufacturing process used to fabricate the body **510** of component **500**. Thus, the short rods **531** and the hollow tubes **532** may be fabricated from the same additive manufacturing material used to fabricate the body **510**. In alternative embodiments, the short rods **531** and the hollow tubes **532** may be fabricated from a material other than the additive manufacturing material used to fabricate the body **510**. In addition, the short rods **531** and the hollow tubes **532** may be fabricated from two different materials.

In the above described embodiments, the damping element and the damping medium occupy at least 50% of the volume enclosed by the cavity. More particularly, 50% to 100% of the volume enclosed by the cavity is filled with the damping element and the damping medium.

FIG. **6** is a flowchart of an exemplary method **600** of forming a vibration-damping component by an additive manufacturing process. In the method **600**, damping elements are advantageously formed in-situ during the additive manufacturing process used to fabricate the component. The method **600** comprises a step **601** of forming a body of the component from an additive manufacturing material by an additive manufacturing process; a step **603** of forming a cavity within the body during the additive manufacturing process, the cavity having at least one through hole connecting the cavity and an outside space of the component; a step **605** of forming a damping element within the cavity during the additive manufacturing process, the damping element having a relative motion when the component vibrates; a step **607** of injecting a damping medium containing a viscoelastic material into the cavity through the at least one through hole; and a step **609** of closing the at least one through hole. The steps **601**, **603**, **605** may performed simultaneously because they all happen during the additive manufacturing process.

In some embodiments, in step **603**, a cavity having a first through hole and a second through hole may be formed within the body of the component. In step **607**, the damping medium containing a viscoelastic material is injected into the cavity through the first through hole. The second through hole is to let air out during the injection. In step **609**, both the first and the second through holes are closed.

In some embodiments, the step **605** of forming a damping element within the cavity comprises introducing a damping element, such as powder or particles, into the cavity. Unsolidified additive manufacturing material used to fabricate the body of the component may be enclosed within the cavity to act as the damping element by leaving the unsolidified manufacturing material within the cavity. Alternatively, other materials may be enclosed within the cavity to act as the damping element by adding other materials to the cavity before the cavity is completely formed, or enclosed.

In alternative embodiments, the step **605** of forming a damping element within the cavity may comprise selectively solidifying additive manufacturing materials used to fabricate the body of the component to obtain a solidified element and enclosing the solidified element within the cavity. The additive manufacturing materials for forming the solidified element may be same as the additive manufacturing materials used for fabricating the component, or may be other material different from the additive manufacturing materials used for fabricating the component.

The step **609** of closing the at least one through hole may be completed by welding, brazing. In some embodiments, the at least one through hole may be closed using epoxy.

The above described components and methods enable use of a vibration damper within one or more cavities formed in components, which includes a damping element and a damping medium containing a viscoelastic material surrounding the damping element. The combination of a damping element and a damping medium containing a viscoelastic material could improve vibration damping performance of components. The vibration dampers may be precisely formed and strategically positioned within the components so as to not compromise the structural integrity of the component. Further, through use of additive manufacturing technology, the components and methods described herein enable efficient manufacture and greatly reduce the amount of time and costs needed to fabricate vibration-damping components. When the component vibrates, the relative motion of the damping element induces shear into the damping medium containing a viscoelastic material causing more dissipation of energy. Therefore, in contrast to known articles and methods of manufacturing such articles, the components and methods described herein facilitate fabrication of vibration-damping components, and provide improved damping performance over known articles.

The above described components and methods could be used in various industries, not limited to gas turbine engine, such as wind turbine components and any other long slender components having vibration damping needs. The components and method of this disclosure can also be used in construction industry, for example, some components of bridge and skyscraper.

Although specific features of various embodiments of the invention may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the invention, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A vibration-damping component, comprising:

a body formed from an additive manufacturing material by an additive manufacturing process and defining a cavity within the body; and

a vibration damper disposed within the cavity and comprising:

a damping-material having a relative motion when the component vibrates; and

a damping medium containing a viscoelastic material surrounding the damping material,

wherein the body is formed of solidified portions of the additive manufacturing material, and

wherein the damping material is formed of unsolidified portions of the additive manufacturing material.

2. The vibration-damping component of claim **1**, wherein the additive manufacturing material comprises at least one of a metal powder, a thermoplastic powder, a photopolymer resin, a thermoset resin, and a thermoplastic resin.

3. The vibration-damping component of claim **1**, wherein the damping material comprises powders or particles suspended in the viscoelastic material.

4. The vibration-damping component of claim **3**, wherein the powders or particles have particle size in a range of 5-1000 microns.

5. The vibration-damping component of claim **1**, wherein the damping material is formed of unsolidified portions of the additive manufacturing material used to form the body of the component left inside the cavity during the additive manufacturing process.

6. The vibration-damping component of claim **3**, wherein the powders or particles are introduced into the cavity during the additive manufacturing process.

7. The vibration-damping component of claim **1**, wherein the viscoelastic material comprises epoxy resin or polyurethane.

8. A gas turbine engine comprising:

a combustor assembly including a plurality of fuel mixers;

a turbine assembly including a plurality of turbine blades; and

a compressor assembly including a plurality of fan blades,

wherein at least one of the fuel mixers, the turbine blades, and the fan blades comprises the component according to claim **1**.

9. A method of forming a vibration-damping component, comprising:

forming a body of the component from an additive manufacturing material by an additive manufacturing process;

forming a cavity within the body during the additive manufacturing process, the cavity having at least one through hole;

forming a damping material within the cavity during the additive manufacturing process, the damping material having a relative motion when the component vibrates;

injecting a damping medium containing a viscoelastic material into the cavity through the at least one through hole; and

closing the at least one through hole,

wherein the body is formed of solidified portions of the additive manufacturing material, and

wherein the damping material is formed of unsolidified portions of the additive manufacturing material.

10. The method of claim **9**, wherein the at least one through hole is closed by welding or brazing.

11. The method of claim **9**, wherein the at least one through hole is closed using epoxy.

12. The method of claim **9**, wherein forming the damping material comprises introducing powders or particles into the cavity.

13. The method of claim **9**, wherein forming the damping material comprises leaving the unsolidified portions of the additive manufacturing material used to form the body of the component in the cavity.

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